CRATER COMPARISONS

Investigating Impact Craters on Earth and Other Planetary Worlds

PART 1: IDENTIFYING CRATER CHARACTERISTICS

The images below are of impact craters from different planetary worlds in our Solar System. List your observations in the space below. Focus your observations on similarities and differences of the visible characteristics of these features.

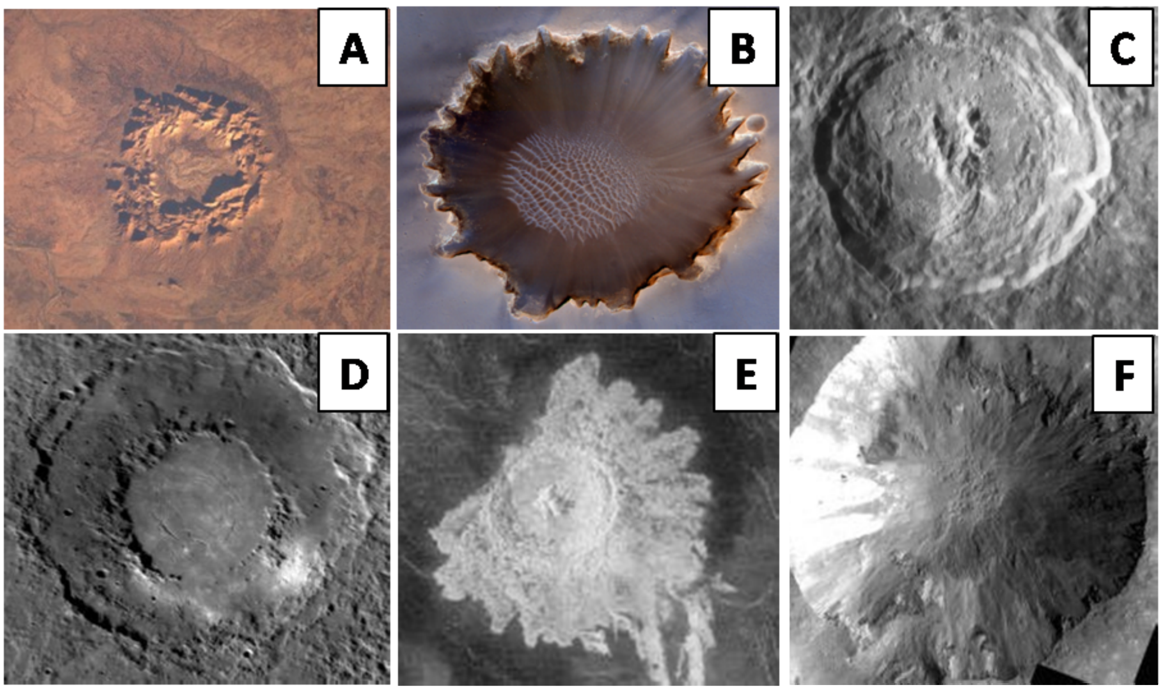


Image Credit: NASA

SIMILARITIES	DIFFERENCES

Based on your observations of the above images, list at least 1 question you have about impact craters in the space below?

PART 2: EXPLORING IMPACT CRATERS AND MAKING INITIAL OBSERVATIONS

A. BACKGROUND INFORMATION

Causes of Impacts

Impact craters are features created on the surface of a planetary body when a meteoroid strikes the surface creating a bowl-shaped hole. Meteoroids can be particles of cosmic dust, parts of asteroids, leftover material from the formation of our Solar System, or even comets – objects made of rock and ice that travel through our Solar System. Small meteoroids burn up in our atmosphere. Those that are large enough to make it through our atmosphere, strike the surface creating an impact crater. The number of impact craters found on the surface of a planet varies, as do the size of these features. Asteroids and fragments of other planets are the most common objects that are the meteorites we find on earth.

Meteoroid: A chunk of rock or ice orbiting the Sun inside the Solar System.

Meteor: What we see when a meteoroid attempts to pass through Earth's atmosphere and burns up.

Meteorite: Left over material that survives the trip through the atmosphere and is found on the surface.

Believe it or not, you have probably seen hundreds of impact craters! Every time you look up at the Moon you are looking at evidence of ancient collisions in our Solar System. As a matter of fact, impact craters are found on most of the rocky (terrestrial) planets and moons in our Solar System. The impact process is the most common process seen across our Solar System.

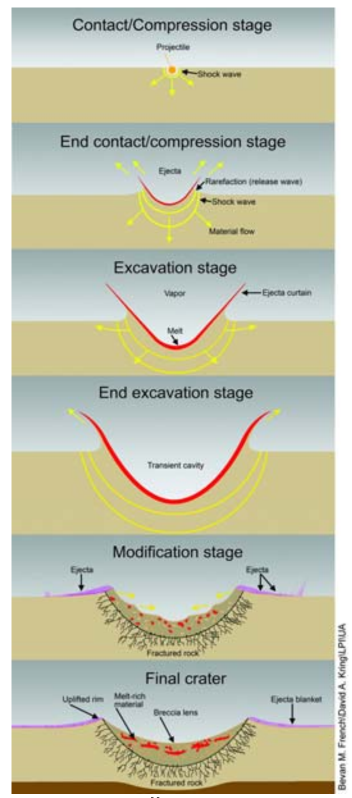


Image Credit: LPI

Formation of Craters

There are three main stages involved in the formation of craters. First, we have a contact/compression stage. This is when a meteorite (a meteoroid that has successfully made it through our atmosphere) traveling 10-15 kilometers per second strikes the surface of a planet. As it strikes, shock waves compress the surface and cause rocky material to almost liquefy or melt. The excavation stage is when material gets ejected or thrown out of the newly formed hole in the ground. The modification stage is when the ejecta settles out onto the surface and material in the walls of the newly formed crater slump. The final crater will continue to be modified by gravity and erosion. The entire crater formation process occurs in seconds and usually the meteoroid is vaporized. Fragments that remain are called meteorites.

Crater Characteristics

There are 5 main parts or characteristics of a crater. These include:

- **Central peak:** An uplifted mound in the floor of the crater.
- **Wall:** The sides of the crater.
- **Floor:** The bottom of the crater.
- **Rim:** The raised area around the edge of the crater.
- **Ejecta:** The material from inside the crater that is thrown our during the impact event. Ejecta can appear as rays or as a blanket of material surrounding the crater.

As shown in the image on the right, the difference between a simple crater and complex crater is that a complex crater oftentimes has a central peak. A central peak is created when melted rock rebounds or gets uplifted during the impact event and then solidifies in that uplifted position. Complex craters are also larger structures and can have material that has slumped along the walls giving them a terraced, step-like, or inner ring appearance.

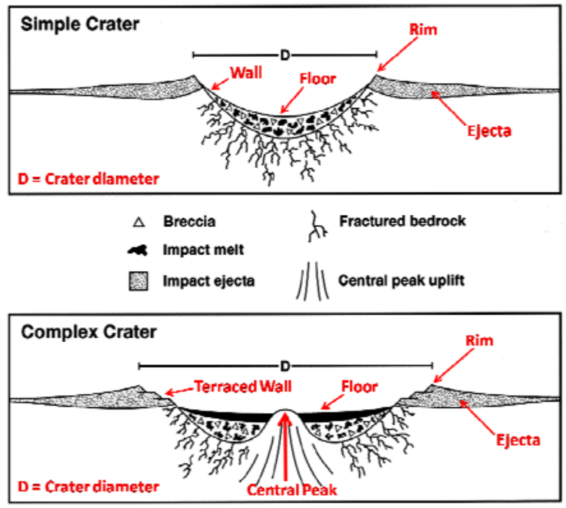


Image Credit: NASA/GSFC

What do Craters Tell Us?

Impact craters open up a window into a planet's history and geology. Once a crater is formed on a planet, making observations of how it is modified or eroded tells us a lot about that planetary world. Craters can be eroded by wind, water, tectonics, or even volcanic processes. They can be modified, covered, or filled in by water, vegetation, sediments (sand, dust, etc), landslides, lava or even ejecta from the formation of other craters.

Geologic principles or rules help scientists use craters as a tool to help understand the sequence of geologic events that took place in a region. Some of these principles include:

- *Principle of Superposition:* This principle states that the order of layers or geologic features found on the surface provide information about which features are older or younger. Features found on top are the youngest.
- *Crater Density:* The more craters on the surface of a planet, the older that surface is.
- *Crater Classification:* The more modified a crater, the older it is. This can be dependent on the planetary surface as well as the environmental factors (geological or biological) that may influence the crater. Generally, the relative age of craters can be determined through the classification of craters in the following categories:
    - Preserved craters = youngest, best preserved craters
    - Modified craters = middle aged craters with evidence of some modification
    - Destroyed craters = oldest craters that have been severely altered

Using Planetary Comparisons to Understand the History of our Solar System

Scientists can learn a lot about the history of our Solar System by studying impact craters. As the impact process is one of the most common processes affecting terrestrial worlds, scientists can look at the relative ages of planetary surfaces and how impacts have changed over time. This includes the frequency of impacts and size of material that have struck the surfaces of planets over time. As scientists consider the role of wind, water, or volcanic processes that may have modified craters, this helps them understand the processes that have shaped (or continue to shape) the surface of a planet or even help determine if life could have ever existed. Comparative planetology allows scientists to use what they know about Earth, to better understand other worlds and vice versa. As scientists make comparisons, they base their conclusions on observations and interpretations along with information known about the planet(s) they are studying. This information includes the composition of the planetary world, temperatures, the atmosphere (if one exists), the interior, the surface features, etc. The more

knowledge scientists have about the planet as a whole, the better they can draw conclusions with supporting evidence. By studying impact craters, scientists can better understand the history of our Solar System, make predictions about potential future impacts, and help uncover information that can help drive future robotic or even human exploration of other worlds.

B. INITIAL OBSERVATIONS

Let's look at the initial set of images from Part 1 of this activity. Images are of craters on Earth (A), Mars (B), Earth's Moon (C), Mercury (D), Venus (E), and an asteroid named Vesta (F).

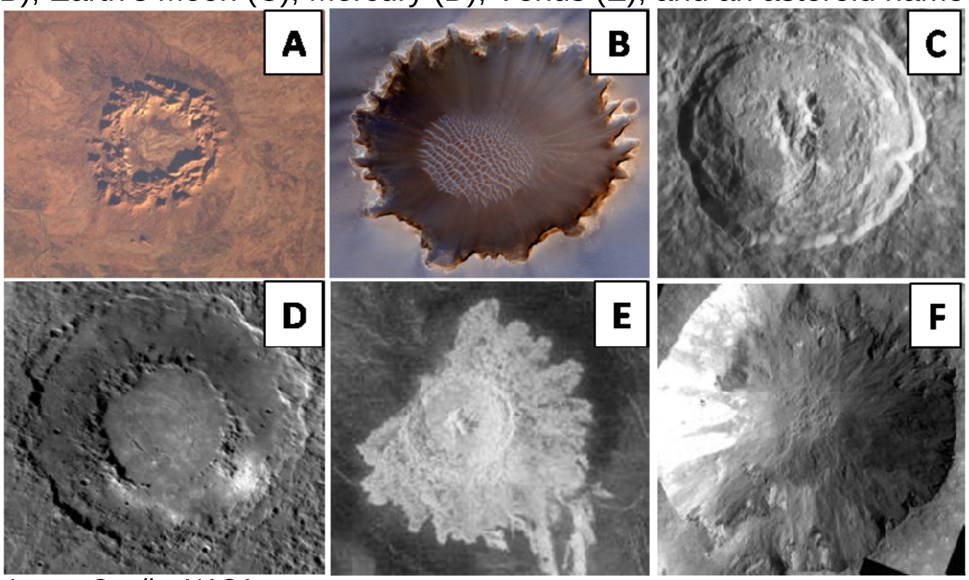


Image Credit: NASA

In the table below, use a check mark to select the characteristics that are visible in each crater:

	Image A	Image B	Image C	Image D	Image E	Image F
Visible rim						
Visible ejecta blanket						
Smooth flat floor						
Filled in or outlined by water						
Central Uplift						
Terraced Walls						

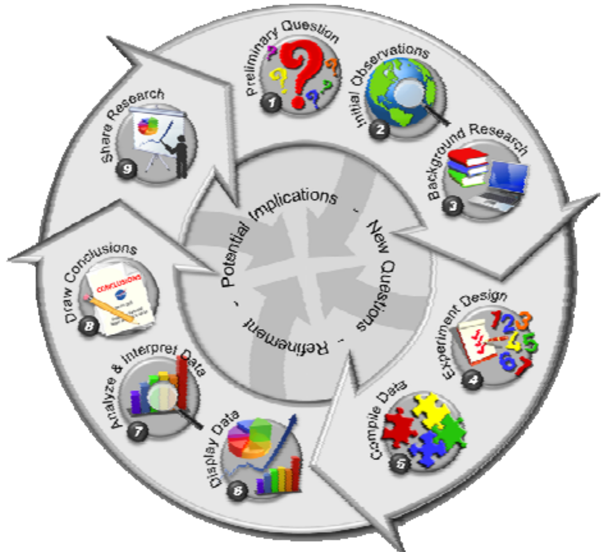
As you completed this exercise, perhaps you wanted to list comments or express the need for additional information you would have liked to have had to help justify your selections. Being able to list these types of miscellaneous notes can be very useful.

Do you think you have enough data to answer the question: **What are the similarities and differences between the characteristics of craters on Earth and other planetary worlds?** With one data point…definitely not. This activity will step you through an investigation to help you answer this question….and perhaps interest you to want to expand on this initial research.

As this investigation will compare the characteristics of craters on Earth to other worlds, it is important to gather data from different planetary bodies. Some of you will focus on images of Earth, Mars, Earth's Moon, or some other world. As your research comes together, it will be essential to share your findings with the class. Let's continue to explore and investigate…

PART 3: CONTINUING OUR CRATER INVESTIGATION

As you work through this investigation, keep in mind that you are modeling skills and practices used by professional scientists. The image on the right is an illustration of the process of science. Scientists use this process when conducting investigations. You have already started completing this process. You have asked a preliminary question (Step 1), made initial observations (Step 2), and gained background knowledge (Step 3) about craters. At this point, we are ready to move into Step 4, creating an experiment design. An experiment design is a plan or methods you will use to conduct your research. By creating a solid plan, this prepares you to collect and compile data consistently so you can then display, analyze, and interpret that data in order to draw conclusions.



Graphic illustrating the process of science
Image Credit: NASA/JSC/ARES/EEAB

The rest of this activity will introduce and guide you through Steps 4 – 8 of the process of science. Sharing your research (Step 9) is a very important part of research. Consider who you might present your research to once your investigation is complete.

PROCESS OF SCIENCE STEP 4: Experiment Design

In this step, it is important that you list your finalized research question and your current hypothesis/es. A hypothesis is an educated guess. It should be based on observations you have made as well as any background knowledge you may have.

Research Question: What are the similarities and differences between the characteristics of craters on Earth and other planetary worlds?

Hypothesis: Based on the images we have observed so far, and what we know about impact craters in our Solar System, we hypothesize that….. [*SUGGESTION: Create an individual hypothesis statement related to each of the five characteristics of craters in addition to crater diameter. Circle the selection that best describes your hypothesis.]*

- Earth craters will be ***smaller, larger, or the same size*** compared to craters on other planetary worlds.
- Earth craters will more often ***have or not have*** a central peak compared to craters on other planetary worlds.
- Earth craters will have a ***more or less*** defined rim compared to craters on other planetary worlds.
- Earth craters will have ***smoother or more terraced*** walls compared to craters on other planetary worlds.
- Earth craters will more often be ***preserved, modified, or destroyed*** compared to craters on other worlds.
- Earth craters will ***more often or less often*** have visible ejecta blankets compared to craters on other worlds.

As part of an experiment design, the following information must be considered:

1. **Image Data Collection:** We will use Crew Earth Observation (CEO) Imagery of Earth provided in the *Crater Comparison* activity. Images were retrieved from the Gateway to Astronaut Photography of Earth website. Additional data/information was retrieved from the Earth Impact Database website.
2. **Specific Data to Collect:** We will log the following information from each image:
   1) Image Identification #; 2) Crater name (if known); 3) Latitude (N); 4) Longitude (E); 5) Planetary Body; 6) Geographic location (country or region)
   Additional data that focus on visible observations include: 7) Crater diameter (km); 8) Central Peak (yes, no, unsure); 9) Crater Walls (smooth, terraced, none visible, not clear); 10) Rim Definition (distinctly raised, somewhat raised, barely raised, not visible); [Not visible = filled in with water or completed eroded]; 11) Crater Classification (preserved, modified, destroyed); 12) Visible Eject Blanket (yes, not, unsure); 13) Miscellaneous notes or observations; 14) Sketches of craters.
3. **Number of Images:** We will log data from images of 8 different craters on Earth and at least 8 craters from other worlds.
4. **Geographic Regions:** We will not focus on any particular region.
5. **Other Data Sets:** For other planetary bodies we will look at images provided in the *Crater Comparison* activity. Images were retrieved from the JPL Planetary Photojournal website.
6. **Measurements:** We will make estimated measurements of craters based on scale bars or measurement lines provided.
7. **Sources:** Gateway to Astronaut Photography of Earth (http://eol.jsc.nasa.gov); Earth Impact Database (http://www.passc.net/EarthImpactDatabase/index.html); JPL Planetary Photojournal (http://photojournal.jpl.nasa.gov/).

It is important to log your data consistently. Notice on the data table sample provided, the column headings provide specific details as to the information you should log. For example, the column heading for crater diameter states "**Crater Diameter (km)**". By including (km) in the column title, it signifies that all diameters logged are in km. As you log the diameter of each crater, only include the diameter measured. Do not include *km* with each entry. This will allow you to more easily sort information on your spreadsheet if desired.

The details listed for the visible observations are very specific details that will also allow you to make common comparisons among Earth craters as well as your observations of craters on other planetary worlds. Make additions or changes as you see fit...just make sure you are consistent as you log your data. To help the class complete this investigation, as you work in groups, some groups will focus on impact craters on Earth, while others look at impact craters on other planetary worlds.

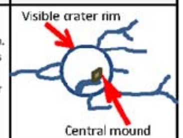
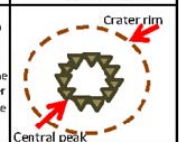
The remaining steps of this investigation include: Step 5: Collect and Compile Data; Step 6: Display Data; Step 7: Analyze & interpret Data; and Step 8: Draw Conclusions.

PROCESS OF SCIENCE STEP 5: Collect and Compile Data

Shown below are a data table for craters on Earth and an additional data table to be used for observations of craters on other planetary worlds. As this research involves comparing craters on Earth with other planetary worlds, the same table headings are provided on both tables. This will allow you to make consistent comparisons of your data.

DATA TABLE - CRATERS ON EARTH

Please note that latitudes are provided as North latitudes [Latitude (N)]. A latitude with a (-) is a South latitude: Example: -27.8 is the same as 27.8S.
Also note that longitudes are provided as East longitudes [Longitude (E)]. A longitude with a (-) is a West longitude: Example: -68.5 is the same as 68.5W.

Image Identification #	Crater Name *(if known)*	Latitude (N)	Longitude (E)	Planetary Body	Geographic location *(country or region)*	Crater Diameter (km)	Central Peak *Yes (Y), No (N), Unsure (U)*	Crater Walls *(smooth, terraced, none visible, not clear)*	Rim Definition *(distinctly raised, somewhat raised, barely raised, not visible) Not visible = filled in with water or completed eroded*	Crater Modification *(preserved, modified, destroyed)*	Visible Ejecta Blanket *Yes (Y), No (N), Unsure (U)*	Miscellaneous notes or observations	Sketch(es) of Craters *(optional)*
ISS012-E-15881	Manicoua-gan	51.5	-68.5	Earth	Canada	51	Y	not clear	not visible	modified	N	Original diameter of crater ~100km. After erosion about 51km remains visible. "Arms"/rivers extend out from the rim. Central mound near cent/right of crater.	
ISS015-E-17360	Gosses Bluff	-23.9	132.3	Earth	Australia	15	Y	none visible	barely visible	modified	N	According to information research about this crater, the well defined bumpy circular feature is part of a central uplift. If you look closely, the rim is barely visible as a faded outer rim. This barely visible outline is the identified crater diameter.	
ISS018-E-14908	Tenoumer	22.9	-10.4	Earth	Mauritania	1.9	N	smooth	somewhat raised	modified	U	The rim of this crater looks soft. The left side in the image appears as though it is more eroded than the right side. There looks to be evidence of eroded ejecta around the rim.	

DATA TABLE - CRATERS ON ________________

Image Identification #	Crater Name *(if known)*	Latitude (N)	Longitude (E)	Planetary Body	Geographic location	Crater Diameter (km)	Central Peak *Yes (Y), No (N), Unsure (U)*	Crater Walls *(smooth, terraced, none visible, not clear)*	Rim Definition *(distinctly raised, somewhat raised, barely raised, not visible) Not visible = filled in with water or completed eroded*	Crater Modification *(preserved, modified, destroyed)*	Visible Ejecta Blanket *Yes (Y), No (N), Unsure (U)*	Miscellaneous notes or observations	Sketch(es) of Craters *(optional)*

As you log your observations, be sure to be as consistent as possible. If you use are able to create a spreadsheet to log your data, this will allow you to more easily display your data in the next step.

The first six columns on the data tables are considered metadata. This is standard information from the images/data you are observing. This includes the image identification number, the name of the crater (if known), the latitude, longitude, planetary body name, and the geographic location.

The remaining columns of information include your observations of the crater(s) in each image. As previously mentioned, by having specific and consistent choices/considerations, you will be able to make consistent comparisons of your observations of craters on Earth and other planetary worlds.

PROCESS OF SCIENCE STEP 6: Display Data

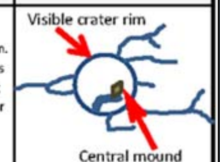
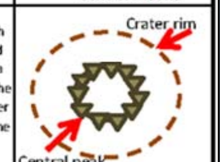
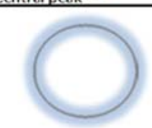
After you finish collecting and compiling data from at least 8 craters, it is time to display that data so you can make observations and later analyze the data. The three parts of Step 6 are to: 1) **Decide how to display your data** (Sorted Data Table(s), Graphs, Maps, Image Illustrations); 2) **Create your data displays**; and 3) **Make observations**. As you create your own data displays, be sure to include 2-3 observations of each display. Use the Data Displays and Observations listed below as examples.

DATA TABLES

Your completed or master data table provides you with very useful information. Sorting your data is important as it allows you to look for patterns. Remember, with <u>each</u> data display be sure to list 2-3 observations.
The table below has been sorted by *crater diameter.*

DATA TABLE - CRATERS ON <u>EARTH</u>

Please note that latitudes are provided as North latitudes [Latitude (N)]. A latitude with a (-) is a South latitude: Example: -27.8 is the same as 27.8S.
Also note that longitudes are provided as East longitudes [Longitude (E)]. A longitude with a (-) is a West longitude: Example: -68.5 is the same as 68.5W.

Image Identification #	Crater Name *(if known)*	Latitude (N)	Longitude (E)	Planetary Body	Geographic location *(country or region)*	Crater Diameter (km)	Central Peak *Yes (Y), No (N), Unsure (U)*	Crater Walls *(smooth, terraced, none visible, not clear)*	Rim Definition *(distinctly raised, somewhat raised, barely raised, not visible) Not visible = filled in with water or completed eroded*	Crater Modification *(preserved, modified, destroyed)*	Visible Ejecta Blanket *Yes (Y), No (N), Unsure (U)*	Miscellaneous notes or observations	Sketch(es) of Craters *(optional)*
ISS012-E-15881	Manicoua-gan	51.5	-68.5	Earth	Canada	51	Y	ot clear	not visible	modified	N	Original diameter of crater ~100km. After erosion about 51km remains visible. "Arms"/rivers extend out from the rim. Central mound near cent/right of crater.	
ISS015-E-17360	Gosses Bluff	-23.9	132.3	Earth	Australia	15	Y	none visible	barely visible	modified	N	According to information research about this crater, the well defined bumpy circular feature is part of a central uplift. If you look closely, the rim is barely visible as a faded outer rim. This barely visible outline is the identified crater diameter.	
ISS018-E-14908	Tenoumer	22.9	-10.4	Earth	Mauritania	1.9	N	smooth	somewhat raised	modified	U	The rim of this crater looks soft. The left side in the image appears as though it is more eroded than the right side. There looks to be evidence of eroded ejecta around the rim.	

NOTE:

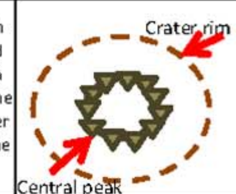
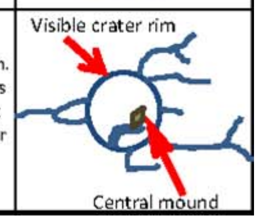
- Observations should state general patterns or notable information the data display is illustrating.
- Observations **do not** attempt to decipher what those patterns mean.
- Observations should generally not be questionable. Everyone should be able to agree on stated observations.

Observation #1: The larger the crater diameter, the less visible the rim definition.
Observation #2: There larger the crater diameter, the more likely it is for the crater to have a central uplift.
Observation #3: Craters with a diameter over 15km appear to have a central uplift.

This table was sorted by *latitude.*

DATA TABLE - CRATERS ON EARTH

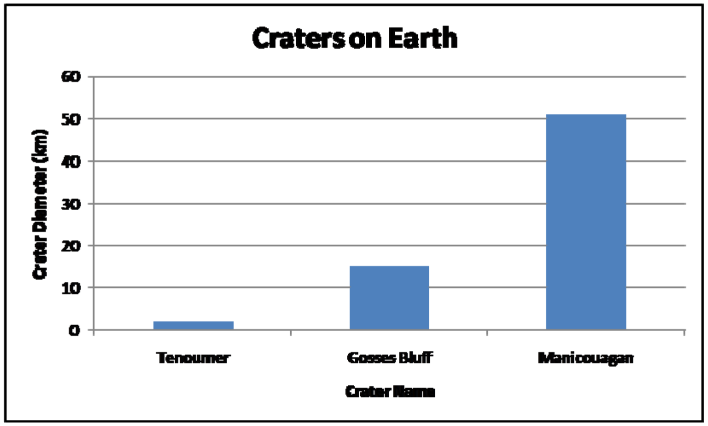
Please note that latitudes are provided as North latitudes [Latitude (N)]. A latitude with a (-) is a South latitude: Example: -27.8 is the same as 27.8S.
Also note that longitudes are provided as East longitudes [Longitude (E)]. A longitude with a (-) is a West longitude: Example: -68.5 is the same as 68.5W.

Image Identification #	Crater Name *(if known)*	Latitude (N)	Longitude (E)	Planetary Body	Geographic location *(country or region)*	Crater Diameter (km)	Central Peak *Yes (Y), No (N), Unsure (U)*	Crater Walls *(smooth, terraced, none visible, not clear)*	Rim Definition *(distinctly raised, somewhat raised, barely raised, not visible) Not visible = filled in with water or completed eroded*	Crater Modification *(preserved, modified, destroyed)*	Visible Ejecta Blanket *Yes (Y), No (N), Unsure (U)*	Miscellaneous notes or observations	Sketch(es) of Craters *(optional)*
ISS015-E-17360	Gosses Bluff	-23.9	132.3	Earth	Australia	15	Y	none visible	barely visible	modified	N	According to information research about this crater, the well defined bumpy circular feature is part of a central uplift. If you look closely, the rim is barely visible as a faded outer rim. This barely visible outline is the identified crater diameter.	
ISS018-E-14908	Tenoumer	22.9	-10.4	Earth	Mauritania	1.9	N	smooth	somewhat raised	modified	U	The rim of this crater looks soft. The left side in the image appears as though it is more eroded than the right side. There looks to be evidence of eroded ejecta around the rim.	
ISS012-E-15881	Manicoua-gan	51.5	-68.5	Earth	Canada	51	Y	not clear	not visible	modified	N	Original diameter of crater ~100km. After erosion about 51km remains visible. "Arms"/rivers extend out from the rim. Central mound near cent/right of crater.	

Observation #1: Craters in both the southern and northern latitudes are modified.
Observation #2: Craters in both the southern and northern latitudes have central uplifts.
Observation #3: Craters in both the southern and northern latitudes have no easily detectable ejecta blankets.

GRAPHS

Graphs can allow you to visualize and illustrate your data, again allowing you to look for patterns. The graph below is showing the diameters of different craters on Earth.



Observation #1: Crater diameters on Earth, based on those observed, range from ~2km to ~50km.

Observation #2: There are not many craters of similar sizes on Earth

Observation #3: The range of craters sizes on Earth is wide.

Note: The more data you graph, the easier it is to make observations and look for notable patterns.

MAPS

Maps can allow you look for local, regional, or global patterns. The map shown here indicates the global distribution of impact craters (referred to as structures) on Earth.

Observation #1: Impact Craters are located on *most* continents on Earth.

Observation #2: The craters we observed are in North America, Africa, and Australia.

Observation #3: There are no impact craters found in Greenland or Antarctica.

World Impact Structures Sorted according to Location

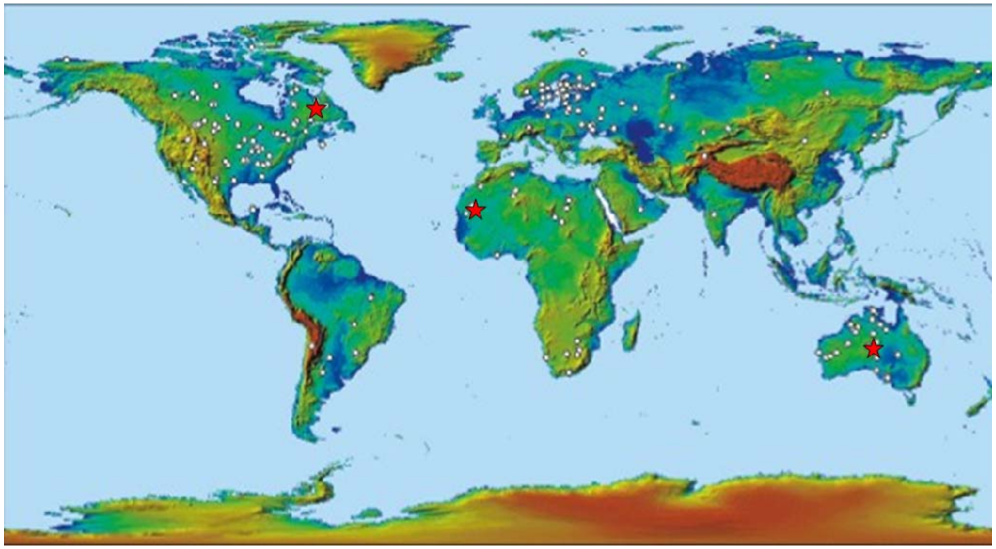


Image Credit: Earth Impact Database: http://www.unb.ca/passc/ImpactDatabase/CILocSort.html

★ = craters observed

IMAGE ILLUSTRATIONS

To help you illustrate your observations so readers of your research have a better understanding of your observations, image illustrations can be very powerful. See the two image illustration examples below.

BARELY VISIBLE RIMS

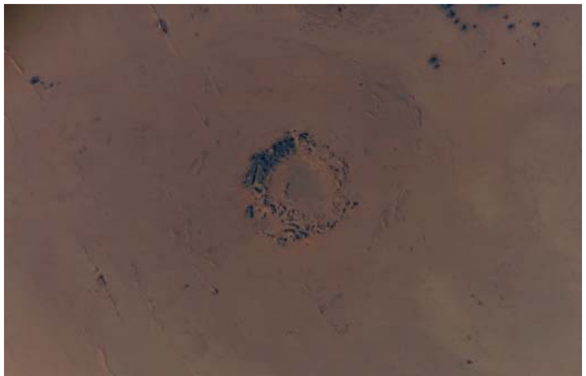


Image Illustration #1: Most craters on Earth appear to be extremely modified (eroded). Rims like the one shown in the image above are often times barely visible. (ISS014-E-11841: Oasis Crater)

CENTRAL PEAKS

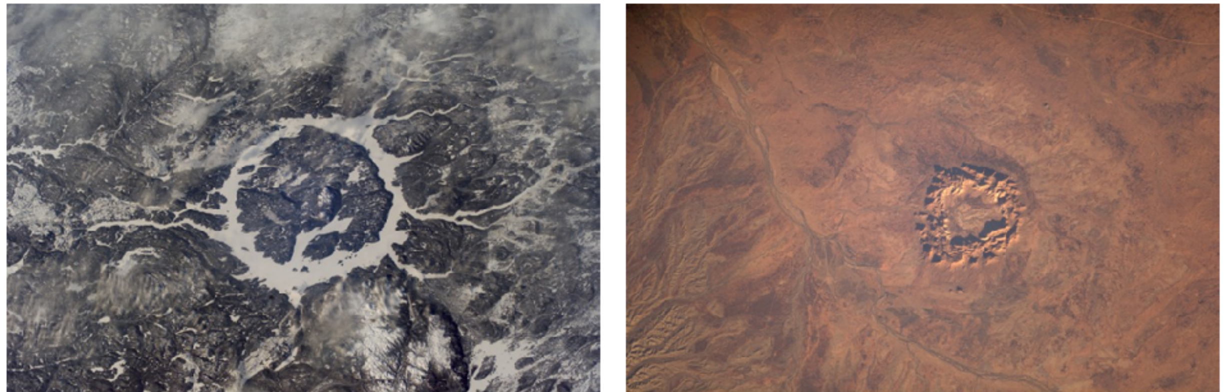


Image Illustration #2: Very few craters on Earth have central peaks. As these craters are extremely modified, the central peaks can easily go unnoticed. Original crater diameters shown here were 100km (Manicouagan ISS012-E-15881) and 22 km (Gosses Bluff ISS015-E-17360).

IMAGE ILLUSTRATION #1:
Observation #1: Image caption indicates that most craters on Earth appear to be extremely modified.

Observation #2: Crater in this image appears to be extremely eroded with hardly any visible detection of a wall, rim, or ejecta.

IMAGE ILLUSTRATION #2:
Observation #1: Central peaks in these images are very difficult to identify.

Observation #2: The terrain/environment of these two impact craters appear to be very different.

Observation #3: The original crater diameters (retrieved from the Earth Impact Database) are larger than the crater diameter measured using the measurement reference lines provided with each image. Manicouagan has a current measured diameter of ~51km; diameter of Gosses Bluff is ~15km.

PROCESS OF SCIENCE STEP 7: Analyze & Interpret Data

Once you display your data and have made observations of those data displays, you are ready to do one of the most important steps of your research – analyze and interpret the data. Analysis and interpretation of data are done by thinking about how specific observations and knowledge you have directly relate to your question. Your goal is to be able to draw conclusions about your research with supporting evidence.

As you analyze your data, focus on your research question and hypothesis/es.

Research Question: What are the similarities and differences between the characteristics of craters on Earth and other planetary worlds?

Hypothesis: Based on the images we have observed so far, and what we know about impact craters in our solar system, we hypothesize that….. [This should be the original hypotheses statements you made earlier.]

- Earth craters will be *smaller, larger, or the same size* compared to craters on other planetary worlds.
- Earth craters will more often *have or not have* a central peak compared to craters on other planetary worlds.
- Earth craters will have a *more or less* defined rim compared to craters on other planetary worlds.
- Earth craters will have *smoother or more terraced* walls compared to craters on other planetary worlds.
- Earth craters will more often be *preserved, modified, or destroyed* compared to craters on other worlds.
- Earth craters will *more often or less often* have visible ejecta blankets compared to craters on other worlds.

As part of Step 7, each group should fill out the *Analysis and Interpretation of Data* table for the planetary world you focused your observations on. As you analyze and interpret data, focus on: 1) Specific observations from Data Displays; 2) Interpretation of what those observations mean with respect to your question/hypotheses; and 3) Evidence that support your interpretations.

Consider including information that focuses on each observation category you logged on your data tables. For example, you made observations of 1) crater diameter; 2) existence of central peaks; 3) crater walls; 4) rim definition; 5) crater classification; 6) visible ejecta. As a part of your conclusions, you should be able to provide evidence of the similarities and differences between craters on Earth and other planetary worlds in each of those categories.

The table on the next page provides starting information on two of these categories: c*rater modification* and c*entral peaks*. This table is not complete as it requires additional data to be collected for Earth. You will also notice a sample table for other planetary worlds you can use as a starting example. As you look over this table, notice how the information listed in column 1 comes directly from observations that were listed with created data displays. This is noted in parenthesis after the observation.

As previously mentioned, observations are very important in that they basically state patterns or notable information illustrated in a data display. In Step 7, as you think about how those observations apply to your research, you are analyzing and interpreting the data. Your interpretation (column 2) of a listed observation compared to someone else's interpretation can vary. This is why it is important to have supporting evidence (column 3) to back up your interpretations. This will also help you draw your overall conclusions.

In Step 7 you will: 1) Fill out an *Analysis and Interpretation of Data* table; and 2) Share your analysis with the class.

Table focusing on data collected from Earth craters:

ANALYSIS AND INTERPRETATION OF DATA **Planetary World: EARTH**		
Specific Observation from Data Display	**Interpretation(s) of What Observation Means with Respect to Your Question and/or Hypothesis**	**Evidence That Supports Your Interpretation** (from specific data displays and/or background knowledge)
1. CRATER CLASSIFICATION: Most craters on Earth appear to be extremely modified (Earth Image Illustration #1, Observation #1)	Impact craters on Earth are mostly modified and are therefore not very recent (not very young).	Earth has weathering and erosion processes that modify the craters on Earth.
2. CENTRAL PEAKS: Craters with a diameter over 15km appear to have a central uplift. (Earth Data Table, Observation #3)	The majority of impact craters on Earth are simple craters.	Complex craters are generally large structures. Earth has much smaller craters than those observed on other planetary worlds. (See Earth Graph #1 and ….)
3. CRATER DIAMETER… Be sure to list a specific observation you listed with one of your data displays….	Describe how this observation can be interpreted – what does it tell you about *crater diameter* in craters on Earth (or the planetary world you made observations of).	Provide additional supporting evidence that support your interpretation. Did you illustrate this point in another data display; did you read something about this in the text provided or somewhere else?

Table focusing on data collected from planetary craters:

ANALYSIS AND INTERPRETATION OF DATA **Planetary World: ____________________________**		
Specific Observation from Data Display	**Interpretation(s) of What Observation Means with Respect to Your Question and/or Hypothesis**	**Evidence That Supports Your Interpretation** (from specific data displays and/or background knowledge)
1. CRATER CLASSIFICATION: Most craters on ___________ (*planetary world*) appear to be ________ (*classification*). Image Illustration #___, Observation #___)	Impact craters on _____________ (*planetary world*) are ______________________ (*classification*) and are therefore ___________________ (*interpretation of age*).	______________ (*planetary world*) has ______________________ processes that modify the craters on the surface.
2. CENTRAL PEAKS: Craters with a diameter over ______km appear to have a central uplift. (__________ (*planetary world*) Data Table Observation #____);	Most impact craters on _________ (*planetary world)* are ___________ (*simple or complex)* craters.	Complex craters are generally large structures. ____________ (*planetary world)* has much ____________ (*larger /smaller)* craters than those on other planetary worlds. (See ________ (*data display)* Observation #___)
3. CRATER DIAMETER… Be sure to list a specific observation you listed with one of your data displays….	Describe how this observation can be interpreted – what does it tell you about *crater diameter* in craters on Earth (or the planetary world you made observations of).	Provide additional supporting evidence that support your interpretation. Did you illustrate this point in another data display; did you read something about this in the text provided or somewhere else?

Use this blank *Analysis and Interpretation of Data Table* and additional paper, as necessary.

ANALYSIS AND INTERPRETATION OF DATA: **Planetary World: ______________________**		
Specific Observation from Data Display	**Interpretation(s) of What Observation Means with Respect to Your Question and/or Hypothesis**	**Evidence That Supports Your Interpretation** (from specific data displays and/or background knowledge)

SHARING YOUR ANALYSIS:
Be prepared to share information you have included in you *Analysis and Interpretation of Data* table. As you present your information: 1) Be prepared to discuss your information related to all 6 crater characteristics and, 2) Be prepared to show any related data displays that allow you to illustrate your specific observations and help support your interpretations.

As you listen to each group's presentation, be prepared to contribute additional information as you see fit. In the table below, fill in the names of the planetary worlds you have investigated. Take notes so you can later draw conclusions about this research.

SUMMARY TABLE (use additional paper, as necessary)

	Earth	____________________	____________________	____________________
Crater Diameter				
Existence of Central Peaks				
Crater Walls				
Rim Definition				
Crater Classifica-tion				
Visible Ejecta				
Other Notes				

PROCESS OF SCIENCE STEP 8: Draw Conclusions

Now that you have completed all the above steps, you are now ready to draw conclusions about your question and hypothesis. This is an essential part of your investigation as it allows you to synthesize your overall research and state your results. It also allows others to expand or build on your research in the future.

1**. RESEARCH QUESTION:** *What are the similarities and differences between the characteristics of craters on Earth and other planetary worlds?*

Based on your research and analysis of data, what do you think is the answer to your question? Be sure to summarize supporting evidence.

2. **HYPOTHESIS:** Based on your research and analysis of data, indicate whether each of you hypotheses were supported or refuted? Summarize pertinent evidence.

HYPOTHESIS (Circle the choice that indicates your original hypothesis)	**Supported or Refuted**
Earth craters will be *smaller, larger, or the same size* compared to craters on other planetary worlds.	
Earth craters will more often *have or not have* a central peak compared to craters on other planetary worlds.	
Earth craters will have a *more or less* defined rim compared to craters on other planetary worlds.	
Earth craters will have *smoother or more terraced* walls compared to craters on other planetary worlds.	
Earth craters will more often be *persevered, modified, or destroyed* compared to craters on other worlds.	
Earth craters will *more often or less often* have visible ejecta blankets compared to craters on other worlds.	

Include a summary of pertinent evidence:

WHAT DOES IT ALL MEAN?

As part of any research investigation, it is important to think about the bigger picture. What are the potential implications of this research, why is it important, and what does it all mean? The research you have conducted provides you with useful information related to one of the most dominant processes within our Solar System – the impact process. As you have learned, there are chunks of rock or ice (comets, asteroids, fragments of planets) that have impacted planetary surfaces (including Earth) in our Solar System throughout history. Scientists are able to use specialized dating techniques that allow them to examine rocks in areas impacted to determine actual ages of craters on Earth. For example, one of the youngest, best preserved craters on Earth is Barringer Crater in Arizona. This simple crater is ~50,000 years old and is ~1.2km in diameter. One of the oldest craters on Earth is the Vredefort crater in South Africa. This complex crater is over 2 billion years old and is ~160 km in diameter. While we are currently unable to visit other worlds to determine actual ages of planetary craters, crater density allows us to determine the relative ages of craters and planetary surfaces. Additionally, the modification of craters reveals the geological and/or biological processes that have shaped the surfaces of planetary worlds. In short, impact craters open up a window into the history of our Solar System.

Based on your investigation, discuss the answers to the following questions. Make additional observations as necessary:

1. Of the planetary worlds you investigated as a class, which planetary world has the "oldest" surface, which has the youngest surface? What does that tell you about the processes affecting those worlds? Explain your answer.

2. Which do you think are older: large complex craters or small simple craters? What does that tell you about the size of materials that may be have impacted planetary worlds early in the history of the Solar System versus the size of materials that have more recently impact surfaces? Explain your answer.

3. If the Earth or other planetary worlds were to be impacted by an object in the future, do you think this object would likely be relatively large or small? Explain your answer.

4. NASA plans to send astronauts to visit another planetary world in the future to help us better understand our Solar System. If you had the opportunity to choose which planetary world to visit, which would you choose and why?